# Implementation of a Semantic Wave-Based Simulation Computing Platform for Digital Infrastructure Literacy of High School Students

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https://doi.org/10.17977/um065.v6.i9.2026.14

**Article history**
Submitted: 12 June 2026
Revised: 10 July 2026
Accepted: 11 July 2026
Published: 12 July 2026

**Keywords**
Classroom action research
Digital infrastructure literacy
Distributed computing
Informatics education
Semantic wave

**Abstract**
The background of this research is based on students' low understanding of the concept of inter-computer collaboration which is abstract and difficult to visualize through conventional learning. This research aims to improve students' digital infrastructure literacy through the implementation of a Semantic Wave-based Distributed Computing learning platform and simulations in the classroom. This research used the Classroom Action Research (CAR). The participants were 30 grade XI students majoring in informatics. Data collection was carried out through learning outcome tests based on cycles, student responses, observation sheets, worksheets, and reflection notes. Quantitative data were analyzed using descriptive statistics and paired sample t-tests, while qualitative data were analyzed thematically based on student activities, teacher facilitation, and cycle reflections. The results showed a consistent increase in learning outcomes, with the average score increasing from 59.13 in Cycle I to 73.63 in Cycle II and 83.97 in Cycle III. The paired sample t-test showed a significance value of 0.000 in the comparison of the pre-test with the post-test of Cycle I, and 0.001 in the comparison of Cycle I with Cycle II (Sig. <0.05). Qualitative observations showed increased student engagement, collaboration, communication, and the ability to connect simulation experiences with conceptual terms. The semantic wave pattern helped students move from concrete experiences to contextual transitions, and finally to denser abstract understanding (Semantic Density). Therefore, the semantic wave-based learning intervention was effective in improving students' digital infrastructure literacy in distributed computing through meaningful, interactive, and reflective learning.

## 1. Introduction

The rapid transformation of digital technology has made understanding Distributed Computing an increasingly important competency for high school students, especially those in grade 11, and is no longer merely additional material in the Informatics curriculum (Milala et al., 2024). Distributed computing is a concept that allows multiple connected computers (nodes) to work collaboratively to complete a task simultaneously, thereby increasing system efficiency, speed, and reliability. This concept is highly relevant because various digital services that students use daily, such as social media, cloud storage, and e-commerce, operate on distributed systems (Lo et al., 2023). However, distributed computing learning at the high school level still faces various obstacles. Among them, the material tends to be abstract and difficult to visualize, making it difficult for students to understand how intercomputer collaboration occurs in real-world situations, such as load balancing, inter-node communication, and data synchronization (Rahmawati et al., 2025; Astuti et al., 2025). Furthermore, learning approaches, which are still dominated by conventional methods, fail to provide a concrete and interactive learning experience. As a result, students only understand concepts theoretically without being able to relate them to real-world implementations in digital systems.

This situation demonstrates the limited digital infrastructure literacy among students. Although students have used various digital services in their daily lives, they generally still act as passive users who do not yet understand how data is managed, processed, and distributed within a system (Lo et al., 2023). Students lack an adequate understanding of technical concepts, such as throughput, latency, task allocation, inter-node communication, and parallel data distribution and processing mechanisms that affect system performance (Dzattadini et al., 2025; Ritter & Standl, 2023). These limitations make it difficult for students to connect distributed computing concepts with the operational mechanisms of the various digital services they use. The


ISSN: 2797-3174

same problem is also reflected in students' poor understanding of the relationship between throughput, latency, and data processing mechanisms in distributed systems (Dzattadini et al., 2025; Ritter & Standl, 2023). This situation impacts students' low digital infrastructure literacy, particularly in understanding technical aspects such as throughput, latency, and parallel data distribution and processing mechanisms (Dzattadini et al., 2025; Ritter & Standl, 2023). Students tend to memorize concepts without understanding the relationships between components in distributed systems. Therefore, learning innovations are needed that not only explain concepts but also visualize and simulate system operation in a realistic and interactive manner. To address these issues, this research focuses on developing a distributed computing learning platform based on the Semantic Wave approach. This platform is designed as an interactive medium that allows students to understand distributed computing concepts through visualizations, simulations, and activity-based learning experiences. In this platform, students can directly observe how task distribution, communication between nodes, and data processing occur within a distributed system.

Based on these issues, learning innovations are needed that not only convey theoretical concepts but also visualize and simulate how systems operate realistically and interactively. The development of digital learning platforms is a key innovation in Informatics education, particularly in delivering complex materials such as distributed computing. Digital platforms enable visual, interactive, and contextual presentation of materials, enabling students to grasp difficult concepts through more concrete learning experiences. In the context of digital infrastructure literacy, learning platforms serve as a medium to introduce how digital systems work behind the scenes. Through simulations and visualizations, students can directly observe the process of task distribution, inter-node communication, and parallel data processing. This aligns with the principle of learning by doing, where students learn through direct experience and independent exploration. Interactive features such as immediate feedback, problem-based scenarios, and system exploration enable students to develop critical and computational thinking skills more effectively (Feriyanto & Anjariyah, 2024).

The Semantic Wave approach is used as a pedagogical foundation in platform development to bridge students' understanding from concrete contexts to abstract concepts. The learning process is designed in a systematic pattern, starting with simple visualizations or simulations, then linking them to technical concepts such as load balancing, data communication, and system synchronization, and ending with reflection and application of the concepts (Zhao & Zheng, 2024). With this approach, students understand not only the "what" and "how" but also the "why" of a system. This approach is rooted in the Legitimation Code Theory developed by Karl Maton and views learning as a dynamic process of movement between two main poles: semantic gravity and semantic density. Semantic gravity indicates the degree of attachment of knowledge to a specific context. The stronger the semantic gravity, the more concrete, contextual, and understandable the knowledge. Meanwhile, semantic density indicates the level of meaning density and complexity of a concept. The higher the semantic density, the more abstract, dense, and theoretical the concept. The movement between concrete contexts and conceptual abstraction enables students to build a deeper and more structured understanding (Zhao & Zheng, 2024). The application of the Semantic Wave approach in learning is carried out through a systematic pattern. The learning process begins with the presentation of visualizations, simulations, or problems close to students' lives, then connected to technical concepts such as workload sharing, data communication, and system synchronization. Afterward, students are guided to reflect and apply these concepts in more complex situations (Zhao & Zheng, 2024). This approach helps students understand not only what happens and how a system works, but also the underlying reasons behind its mechanisms. Abstract concepts are first explained or unpackaged through simple language and everyday analogies, then gradually repackaged into more complex technical terminology. Thus, the learning process is not linear or flat but rather forms a wave pattern that connects concrete experiences with theoretical concepts (Zhao & Zheng, 2024).

Several previous studies have shown that the Semantic Wave approach can improve students' conceptual understanding and computational reasoning by helping them connect practical experiences with theoretical concepts (Ritter & Standl, 2024). Transformative learning also needs to avoid the constant use of technical terms without explanation, as high semantic density and weak semantic gravity can lead to confusion. Conversely, providing concrete examples without connecting them to theoretical concepts can hinder students from achieving expected academic competencies (Zhao & Zheng, 2024). Therefore, integrating concrete experiences with conceptual abstraction is crucial in learning complex technological material. Previous research also shows that experiential learning through simulations, digital exploration, and problem-based learning can reduce students' cognitive load and improve knowledge retention (Mubarok et al., 2024). An experiential approach can help develop computational thinking skills because students are directly involved in analyzing problems and observing the workings of a system (Feriyanto & Anjariyah, 2024). The integration of concrete experiences into digital environments can also bridge the gap between abstract concepts and practical understanding (Zhao & Zheng, 2024). In addition to cognitive aspects, a positive and stress-free learning environment can increase students' confidence when facing complex material (Masayu et al., 2025). Emotional engagement formed through enjoyable learning experiences is also a crucial factor in creating sustainable learning (Lo et al., 2023).

The developed platform integrates the principle of learning by doing, allowing students to interact directly with distributed system simulations. Students can observe how a large task is broken down into smaller parts,


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distributed across multiple nodes, processed in parallel, and then recombined into a single, unified result. This feature is expected to provide a more immersive learning experience compared to conventional learning. With this platform, it is hoped that students will improve their digital infrastructure literacy, particularly in understanding how distributed systems operate conceptually and practically. Furthermore, students are also expected to develop computational thinking skills in analyzing and designing distributed system-based solutions (Feriyanto & Anjariyah, 2024).

Although the Semantic Wave approach has been shown to improve students' conceptual understanding and computational reasoning (Ritter & Standl, 2024), research integrating this approach into digital learning platforms specifically designed for distributed computing is limited. Few studies have combined distributed systems visualization, interactive simulations, learning-by-doing principles, and Semantic Waves conceptual movement patterns in a single learning platform to improve high school students' digital infrastructure literacy. This limitation highlights the need to develop learning media that can connect students' concrete experiences with the technical concepts of distributed computing in a gradual and systematic manner. Therefore, this study aims to develop and test the feasibility of a Semantic Wave-based distributed computing platform as an innovative learning medium for improving high school students' digital infrastructure literacy. The results of this study are expected to contribute to the development of informatics learning media that are more interactive, contextual, and relevant to the needs of the digital era, as well as being a solution to overcome students' difficulties in understanding distributed computing concepts more effectively and meaningfully.

# 2. Method

## 2.1. Research Design

This study employed the Classroom Action Research (CAR) method, using a model developed by Stephen Kemmis and Robin McTaggart. The goal is to improve the quality of learning through an iterative cycle consisting of planning, action, observation, and reflection. This method was chosen because it addresses real-world problems in informatics learning, particularly in abstract distributed computing material. This method utilizes a Semantic Wave-based distributed computing platform as a medium to provide a more concrete and interactive learning experience. The CAR study was conducted in three cycles. Figure 1 shows the flow of improvements in the semantic wave-based CAR cycle.

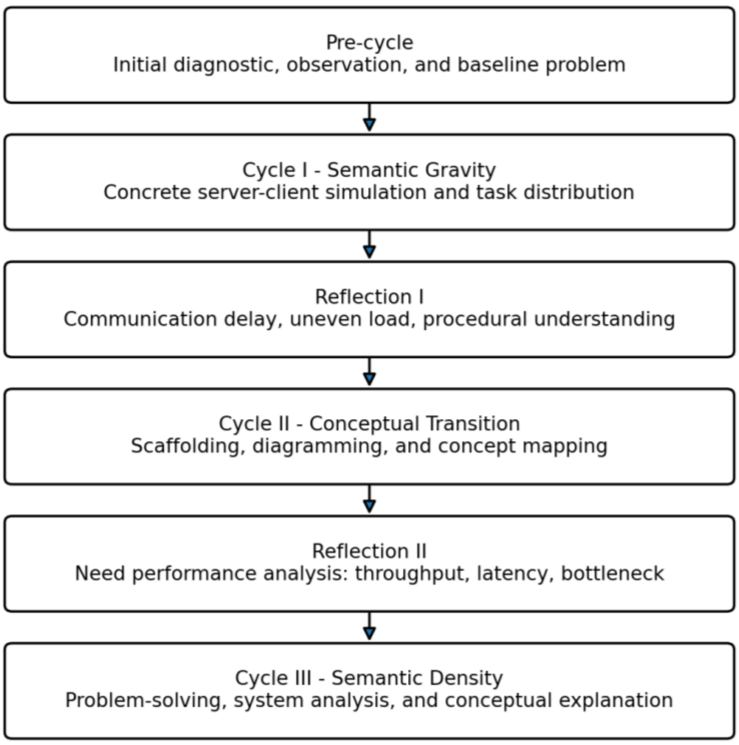


**Figure 1. Research Flow**

In the planning stage, researchers and teachers identified student difficulties in understanding distributed computing, developed learning scenarios, prepared a Semantic Wave-based learning platform, developed student worksheets, and prepared test and observation instruments. The action stage included implementing learning according to the focus of each cycle. The observation stage was conducted to record student activities,


ISSN: 2797-3174

teacher activities, the implementation of learning, and the movement of student understanding from concrete experiences to abstract concepts. The results of observations, tests, student responses, and student worksheets were then analyzed in the reflection stage to determine improvements to be implemented in the next cycle.

This study used a mixed methods approach within a classroom action research framework. Quantitative data were obtained from learning outcome test scores, student response questionnaires, and observation scores, while qualitative data were obtained from observer notes, open-ended responses, student reflections, and student worksheets documents. Both types of data were used in an integrated manner to explain changes in learning outcomes and the process of developing students' conceptual understanding over the three cycles.

## 2.2. Location, Population, and Research Subjects

This research was conducted at one of the senior high schools in Bandung, Indonesia, during the odd/even semester of the 2025/2026 academic year. The target population was eleventh-grade high school students taking Informatics and studying distributed computing. The accessible population included all eleventh-grade students taking Informatics during that academic year.

One class was selected using purposive sampling based on several considerations, including the suitability of the material to the eleventh-grade curriculum, availability of study time, subject teacher approval, and students' perceived difficulty in understanding the abstract concepts of distributed computing. All students in the selected class were included, thus using a total sampling technique for participant selection at the class level.

The study participants were 30 eleventh-grade students, aged 16-17. Prior to participating in the study, the students had received basic material on distributed computing but had not received structured instruction on task allocation between nodes, parallel processing, load balancing, throughput, latency, and data synchronization. Inclusion criteria for this study included students enrolled in the selected classes, participating in at least 100% of the activities across all three cycles, and completing the pretest and posttest. Students who did not meet attendance criteria or did not have complete test data were excluded from the pairwise analysis.

## 2.3. Semantic Wave-Based Learning Intervention

Table 1 shows the learning interventions across cycles. In Cycle I, learning focused on strengthening Semantic Gravity (SG), which involves reducing conceptual abstraction to concrete experiences. In this stage, Distributed Computing concepts were realized through the use of a platform that replicates operating nodes in a distributed system. Students observed and executed scenarios of task distribution, parallel processing, inter-node communication, and result aggregation through interactive platform features. These activities were packaged in a fun, experiential learning approach through hands-on exploration and interaction. Observations focused on student engagement and their ability to understand the system workflow through the platform. In Cycle II, learning focused on the transition from concrete to conceptual understanding. Students began to reflect on their experiences using the platform and then connected them to distributed computing concepts such as parallel work, system coordination, and data communication. The teacher facilitated reflective discussions, analytical simulations, and open-ended questions to foster deeper understanding. If difficulties were encountered in connecting experiences to concepts, support was provided to strengthen understanding. In Cycle III, learning focused on strengthening Semantic Density (SD), namely students' ability to connect concrete experiences to more complex and systematic abstract concepts. Students are challenged to complete problem-based assignments using the platform, such as analyzing the efficiency of task distribution or deploying system performance. They not only understand simulations but are also able to conceptually explain and analyze intercomputer collaboration processes.

**Table 1. Learning Intervention Across Cycles**

| Cycle | Semantic Wave focus | Learning activity | Expected student development |
|---|---|---|---|
| Cycle I | Semantic Gravity | Students simulated a Distributed Computing system by acting as server and clients. They explored task distribution and compared individual versus collaborative processing. | Students obtained concrete experience and could describe the basic flow of server-client collaboration. |
| Cycle II | Concrete-to-conceptual transition | Students processed data in groups, created server-client diagrams, discussed load balancing, and reflected on communication problems. | Students began to connect simulation experience with technical concepts such as parallel processing and load balancing. |
| Cycle III | Semantic Density | Students solved contextual problems involving latency, throughput, data synchronization, and delayed clients. | Students analyzed and evaluated system performance using appropriate conceptual terms. |

The correlation between the Semantic Wave approach (see Figure 2) and the CAR method in this study shows a very close and complementary relationship in improving students' understanding of the concept of


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distributed computing. Semantic Wave serves as a cognitive framework that regulates how students understand knowledge through a movement from the concrete to the abstract and back to a more structured abstract form. Meanwhile, CAR acts as a methodological framework that regulates how the learning process is gradually improved through the cycle of planning, implementation, observation, and reflection. Figure 3 shows the movement of semantic waves across three learning cycles.

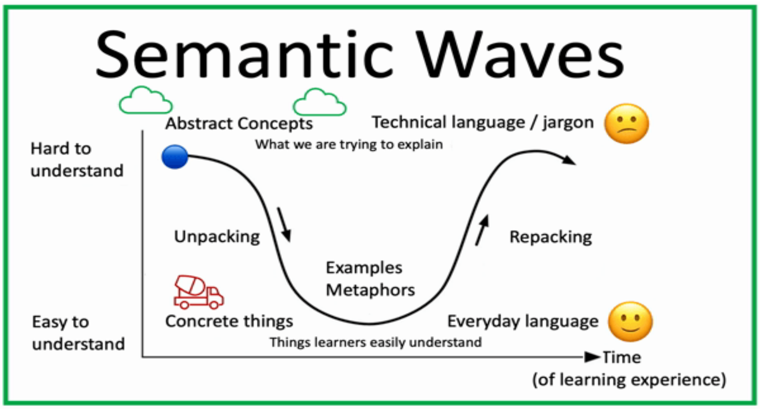


**Figure 2. Correlation of Semantic Wave with CAR Research Method**

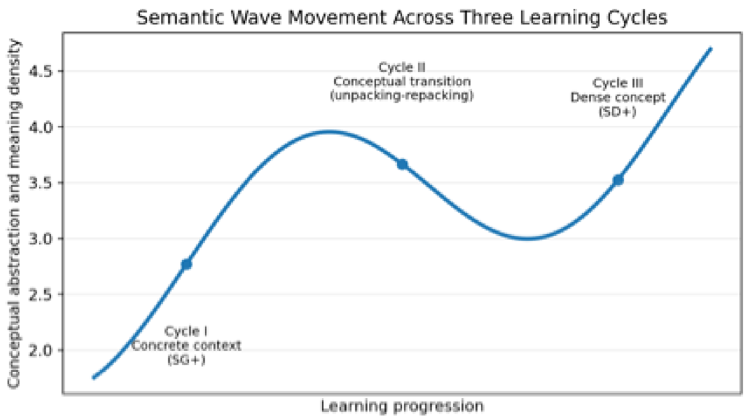


**Figure 3. Semantic Wave Movement Across Three Learning Cycles**

## 2.4. Instruments and Data Sources

The learning outcome test was used to measure students' understanding of distributed computing. The instrument consisted of 10 pretest items and 10 posttest items in multiple-choice format with four answer alternatives. The material measured included the definition of distributed computing, server and client functions, parallel processing, load balancing, data communication, the impact of client delays, and examples of distributed system applications. Each correct answer was given a score of 1 and an incorrect answer a score of 0. Raw scores were converted to a 0–100 scale using the formula:

$$test\ score = \frac{total\ number\ of\ items}{number\ of\ correct\ answers} \times 100 \quad (1)$$

The pretest was administered [before each cycle/before Cycle I], while the posttest was administered at the end of [each cycle/Cycle III]. The use of different but equivalent test formats requires an explanation of the equivalence of indicators, difficulty level, and material coverage.

The student response questionnaire consisted of 20 statements measuring platform ease of use, engagement, conceptual understanding, learning experience, and learning usefulness. Each statement was rated using a four-point scale: 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree. Negative statements were reverse-scored before analysis. The student observation sheet consisted of 10 indicators covering engagement in the simulation, understanding of server-client roles, group collaboration, task allocation, communication, enthusiasm, parallel processing, ability to explain concepts, the relationship between simulation and theory, and participation in discussions and reflection.


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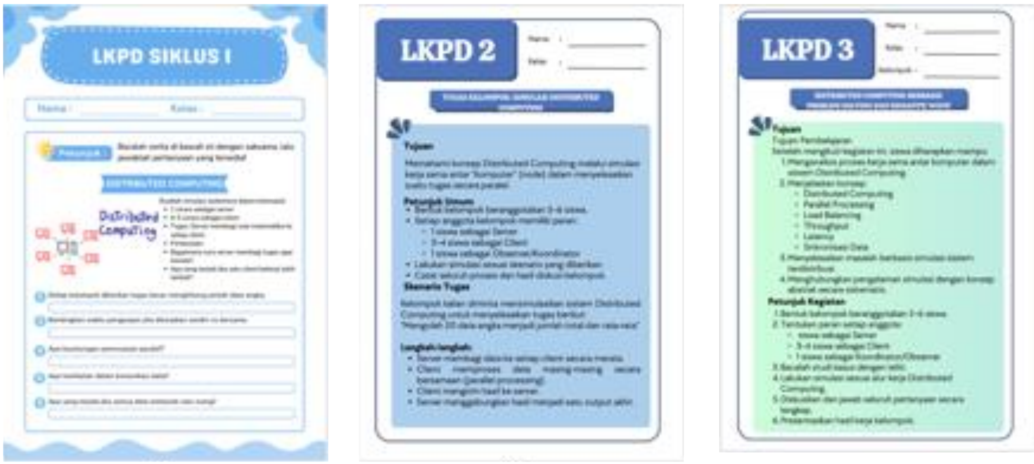
The teacher observation sheet consisted of 10 indicators covering clarity of learning objectives, implementation of the Semantic Wave strategy, simulation quality, student guidance, creating a pleasant learning environment, facilitating discussions, providing scaffolding, linking experiences to abstract concepts, conducting reflections, and classroom management.

Another instrument was the student worksheet document for each cycle. The observation sheets used a four-point scale: 4 = excellent, 3 = good, 2 = fair, and 1 = poor. The worksheet document was used to organize student activities and reflections during each cycle. Figures 4a, 4b, and 4c show the worksheets used in Cycles 1, 2, and 3.




(a) (b) (c)

**Figure 4. The Worksheet Document: (A) Cycle 1, (B) Cycle 2, (C) Cycle 3**

## 2.5. Data Collection and Analysis

Data collection was conducted sequentially in each cycle. First, students completed a pretest to measure initial abilities. Second, teachers implemented learning interventions according to the Semantic Wave focus of the respective cycle. During the learning process, observers assessed student and teacher activities and recorded important events in the field notes section. Third, students completed student worksheets and posttests. Fourth, at the end of each cycle (Cycle III), students completed a response questionnaire. Fifth, researchers and teachers reviewed the test results, observations, student worksheets, and field notes to determine corrective actions for the next cycle. To maintain consistency in intervention implementation, teachers used the agreed-upon lesson plan, student worksheets, time allocation, and simulation stages. Documentation in the form of video recordings, photos, and activity notes was used to review the implementation of the learning and support qualitative analysis.

Data analysis was conducted using two approaches: quantitative and qualitative. Quantitative data were analyzed using descriptive statistics, including means, standard deviations, minimum scores, and maximums. Student response data were analyzed using item means and overall averages. Observational data were summarized using descriptive scores and thematic interpretations. Qualitative data from observation notes and worksheets were used to interpret how students moved from concrete experiences to conceptual understanding.

# 3. Results and Discussion

## 3.1. Student Learning Outcomes Across the Cycle

Table 2 shows student learning outcomes for each cycle. The learning outcomes data show consistent improvement across all three CAR cycles. The average score increased from 59.13 in Cycle I to 73.63 in Cycle II and 83.97 in Cycle III. This pattern indicates that student understanding progressively improved as learning shifted from concrete simulations to conceptual and analytical tasks.

**Table 2. Student Learning Outcomes Data for Each Cycle**

| Comparison | Mean Score 1 | Mean Score 2 | Score Increase | Interpretation |
|---|---|---|---|---|
| Cycle I to Cycle II | 59.13 | 73.63 | 14.50 | Increased |
| Cycle II to Cycle III | 73.63 | 83.97 | 10.33 | Increased |
| Cycle I to Cycle III | 59.13 | 83.97 | 24.83 | Increased substantially |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The consistent increase in the distribution of student scores from Cycle I to Cycle III is clearly visible in Figure 5. In Cycle I, student scores were still in the low to moderate range, with a median of around 59 and one outlier at 45. This indicates that students' initial understanding of the material was still uneven. In Cycle II, the distribution of scores shifted upward with a median of around 74, indicating that most students began to experience progress in understanding after the subsequent learning activities. Meanwhile, in Cycle III, student scores increased again with a median of around 84 and the score range was in the higher category.

The boxplot analysis in Figure 5 shows that Semantic Wave-based learning has a positive impact on the gradual improvement of student learning outcomes. The improvement in learning outcomes reflects the process of student understanding development from the concrete stage to a stronger conceptual understanding. Furthermore, the distribution of scores also shows that improvement was not limited to a small number of students. The minimum score increased from 45 in Cycle I to 72 in Cycle III, while the maximum score increased from 70 to 95. This indicates that the intervention supported both low-achieving and high-achieving students.

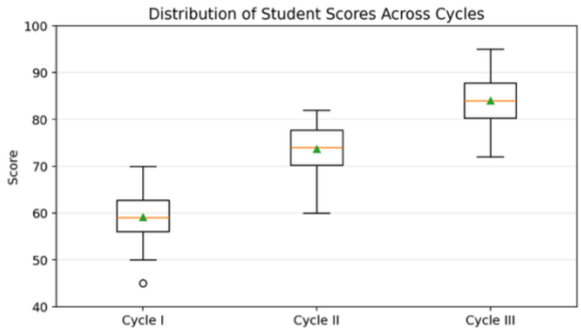


**Figure 5. Distribution of Student Scores Across Cycles**

## 3.2. Student Response to the Semantic Wave-Based Simulation Computing Platform

Based on the results of a descriptive statistical analysis of 20 student responses to the semantic wave-based simulation computing platform (see Table 3), the average score for the 20 questions was above 3.30, indicating that all indicators were in the good to excellent category. This indicates that students generally responded positively to the platform's use in Distributed Computing learning. The highest average score was Q16 = 3.73, followed by Q1 = 3.67 and Q17 = 3.60, indicating that the platform provided a concrete and understandable learning experience, thereby helping students reduce the level of abstraction of the material (see Figure 6). The results of the survey of student responses to the treatment provided indicated that students considered the learning activities useful, interesting, and concrete enough to support understanding.

**Table 3. Descriptive Statistics of Student Response Mean per Item**

| Number | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| 1 | 30 | 3 | 4 | 3.67 | 0.488 |
| 2 | 30 | 2 | 4 | 3.36 | 0.745 |
| 3 | 30 | 2 | 4 | 3.40 | 0.737 |
| 4 | 30 | 1 | 4 | 3.33 | 0.900 |
| 5 | 30 | 1 | 4 | 3.33 | 0.816 |
| 6 | 30 | 2 | 4 | 3.33 | 0.724 |
| 7 | 30 | 2 | 4 | 3.40 | 0.632 |
| 8 | 30 | 2 | 4 | 3.47 | 0.640 |
| 9 | 30 | 1 | 4 | 3.47 | 0.834 |
| 10 | 30 | 1 | 4 | 3.40 | 0.828 |
| 11 | 30 | 2 | 4 | 3.33 | 0.724 |
| 12 | 30 | 2 | 4 | 3.40 | 0.632 |
| 13 | 30 | 1 | 4 | 3.36 | 0.842 |
| 14 | 30 | 2 | 4 | 3.47 | 0.640 |
| 15 | 30 | 2 | 4 | 3.47 | 0.640 |
| 16 | 30 | 3 | 4 | 3.73 | 0.458 |
| 17 | 30 | 3 | 4 | 3.60 | 0.507 |
| 18 | 30 | 2 | 4 | 3.33 | 0.617 |
| 19 | 30 | 1 | 4 | 3.33 | 0.900 |
| 20 | 30 | 1 | 4 | 3.53 | 0.834 |


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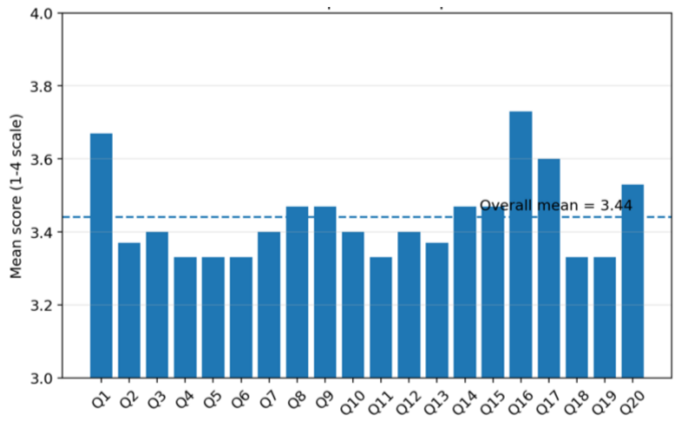


**Figure 6. Student Response Mean per Item**

Regarding data distribution, the standard deviation ranged from 0.458 to 0.900, indicating a low to moderate level of variation in student responses. Low standard deviation values, such as in Questions 16 (0.458) and 17 (0.507), indicate that most students have very similar perceptions of these indicators. Meanwhile, higher standard deviation values, such as in Questions 4 and 19 (0.900), indicate greater variation in responses. This indicates differences in students' perceptions of certain indicators. These differences could be caused by variations in students' initial abilities, their level of adaptation to technology, or differences in learning styles. However, because the average scores remained in the good category, these variations do not indicate a significant problem, but rather differences in individual experiences using the platform.

## 3.3. Observation Results

Table 4 shows the results of observations during the learning process. Observation data indicate that student activity and teacher facilitation were generally strong. Student activity received an average score of 3.70 out of 4, while teacher activity received an average score of 3.80 out of 4. Students were very active in the simulation, understanding the roles of the server and client, participating in reflections, and connecting the simulation to theory. Several aspects were rated good rather than excellent, particularly collaboration consistency, communication between group members, and parallel task completion. These aspects became important points of reflection for improvement in the next cycle.

Observer notes indicated that the classroom atmosphere was more active and enjoyable than in the previous cycle. Students were enthusiastic because they were able to directly practice computer collaboration through server-client roles. They also began to understand load balancing and parallel processing as they experienced task sharing and simultaneous processing. However, some groups still experienced communication delays, especially when one client was slower than the others. This situation became a meaningful learning event because students were able to relate it to latency, bottlenecks, and system performance. Figure 7 shows an example of an observation sheet used during Distributed Computing learning.

**Table 4. Observation Results**

| Observation area | Number of indicators | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Student activity | 10 | 3.7 | 0.48 | 3 | 4 |
| Teacher activity | 10 | 3.8 | 0.42 | 3 | 4 |


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**LEARNING OBSERVATION INSTRUMENT**

**Semantic Wave Strategy in Distributed Computing Learning**

**A. Observation Identity**

- School Name : SMAN 2 Bandung
- Subject : Informatics
- Topic : Distributed Computing
- Class : XI
- Day/Date : Tuesday, May 19, 2026
- Observer : Renisa Nur Kamelia Putri

**B. Instructions for Completion**

Put a check mark (✓) in the score column according to the observation results during the learning process.

**Score Description:**

- 4 = Very Good
- 3 = Good
- 2 = Fair
- 1 = Poor

**C. Student Activity Observation Sheet**

| No. | Observed Aspect | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1. | Students actively participate in the Distributed Computing simulation | | | | ✓ |
| 2. | Students understand their roles as server/client | | | | ✓ |
| 3. | Students are able to work collaboratively in groups | | | ✓ | |
| 4. | Students are able to distribute tasks evenly (load balancing) | | | | ✓ |
| 5. | Students actively communicate with group members | | | ✓ | |
| 6. | Students show enthusiasm during the learning process | | | | ✓ |
| 7. | Students are able to complete tasks in parallel | | | ✓ | |

**Figure 7. Example of the Observation Sheet Used During Distributed Computing Learning**

## 3.4. Discussion

The findings show that Semantic Wave-based Distributed Computing learning improves students' digital infrastructure literacy through a gradual and structured process. This platform-based learning successfully creates a learning experience that is not only cognitively effective but also interactive and conceptually meaningful. The findings also indicate that the integration of the Semantic Wave approach into the platform facilitates students' thinking process from the concrete to the abstract gradually. Students understand not only "what" happens in distributed systems, but also "how" and "why" this process occurs. This is an important indicator in the development of digital infrastructure literacy, where students are able to understand digital systems in a deeper and more applicable way.

In Cycle I, students are introduced to concrete experiences by acting as servers and clients. This stage reduces the abstract nature of Distributed Computing because students can physically observe distributed tasks, parallel work, and communication between members. However, understanding at this stage remains largely procedural. Studies on the use of single-board computers also show that hands-on experience can improve students' understanding of complex concepts, motivation, collaboration, and engagement compared to learning that relies solely on lectures and theoretical explanations (Ariza & Baez, 2022; Álvarez & Hernández, 2026). However, students' understanding in Cycle I was still predominantly procedural. Students were able to follow simulations and explain the server-client workflow, but not all were able to use concepts such as load balancing, latency, throughput, and bottlenecks to explain the simulation results. This condition indicates that hands-on activities do not automatically produce conceptual understanding. Practical experiences need to be accompanied by guiding questions, reflection, visual representation, and the process of repackaging experiences into scientific terms as per David Kolb's Experiential Learning Theory (Kolb, 2013). Within the Semantic Wave framework, this stage reflects the strengthening of Semantic Gravity, where knowledge is placed in a concrete context close to students' experiences before being directed towards more abstract concepts (Meidell Sigsgaard, 2025).

In Cycle II, students began to transition from concrete experiences to conceptual understanding. The use of diagrams, guiding questions, and group reports helped students connect the simulation activities to terms such as Distributed Computing, parallel processing, and load balancing. This transition is important because learning will still be understood if students simply perform the activities without repackaging the conceptualization. The increase in the average score from 59.13 to 73.63 supports the effectiveness of this transition. During implementation, students did not simply act as passive users but actively interacted with the simulation system. Students ran specific scenarios, observed real-time process changes, and explored how variations in task distribution affected system performance. These activities were packaged in a fun, experiential learning approach, increasing students' emotional and cognitive engagement (An Andari, 2025; Salong & Ansiska, 2025). Thus, concepts that were previously abstract and difficult to visualize became more tangible and easier to understand through direct experience.


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Observations in cycle II showed a significant increase in student engagement compared to cycle I. Students appeared more enthusiastic and active in participating in the learning process, as evidenced by their intense interaction with the platform, active participation in group discussions, and strong curiosity about the processes they observed. Educational technology can strengthen student engagement through active interaction with content, learning activities, and social communication (Bond et al., 2020). Furthermore, learning technology plays a crucial role in facilitating student engagement when used as a space for collaboration, exploration, and meaningful interaction (Bedenlier et al., 2020). Furthermore, students began to demonstrate an initial understanding of the workflow of distributed systems, such as how tasks are divided, processed concurrently, and then recombined. From the perspective of Legitimacy Code Theory, this process can be understood as the strengthening of semantic gravity, where learning begins with concrete and contextual experiences before moving on to more complex conceptual understanding (Maton, 2013). This understanding is still procedural in nature, requiring deeper understanding in the next phase.

In Cycle III, learning focused on strengthening Semantic Density (SD), namely students' ability to package concrete experiences gained through using a Semantic Wave-based distributed computing platform into more complex, dense, and systematic abstract concepts (see Figure 8). In Cycle III, students achieved stronger Semantic Density. They were able to analyze system performance, identify pending issues, and connect pending clients to latency and bottlenecks. This stage indicates that students were no longer simply participating in a simulation; they were beginning to reason about how distributed systems work and how their performance could be improved. The average score of 83.97 in Cycle III indicates that the learning intervention successfully guided students toward a more abstract, dense, and systematic understanding.

In the third cycle, students no longer act solely as platform users but begin to transform into simple system analysts and designers. Learning is implemented through problem-based assignments. Problem-based assignments provide students with the opportunity to actively engage in learning by exploring real-world problems, designing possible solutions, and evaluating the effectiveness of their ideas. PBL enhances students' critical thinking and problem-solving skills compared to traditional lecture-based instruction (Lee, 2025) and encourages meaningful learning through collaborative knowledge construction (Yew & Goh, 2016).

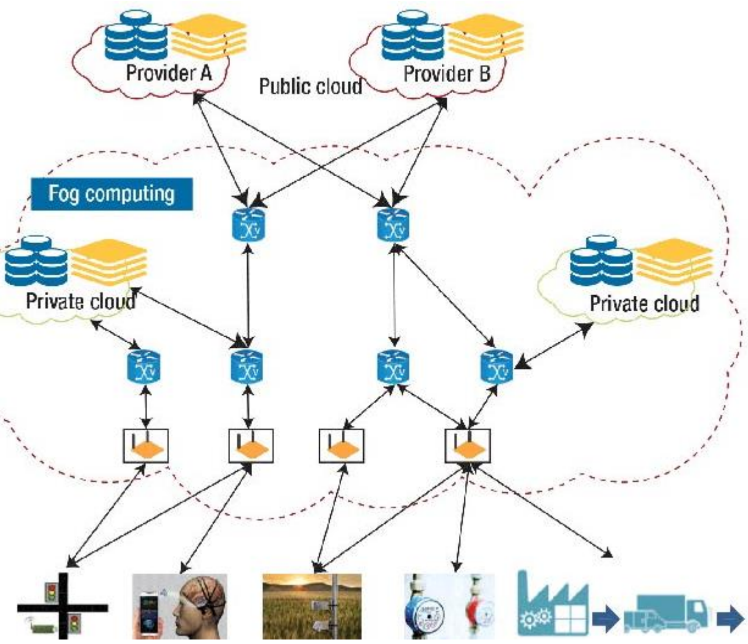


**Figure 8. Semantic Wave-Based Distributed Computing Platform**

Observation results support the quantitative descriptive analysis. Students demonstrated high engagement, active discussion, collaboration, and reflective participation. Observed communication delays between clients provided authentic learning opportunities because students could experience how a small delay in one node can impact the entire system. These findings suggest that classroom simulations can serve as a bridge between real-life experiences and technical concepts.

The results of this study align with both hands-on and simulation-based parallel and distributed computing learning that emphasizes the importance of active interaction, system exploration, collaboration, and contextual experiences in helping students understand abstract concepts. However, the findings of this study demonstrate a more specific contribution because the simulation experience does not stop at procedural mastery but is organized through the Semantic Wave stages from strengthening Semantic Gravity in Cycle I, the concrete-


ISSN: 2797-3174

conceptual transition in Cycle II, to strengthening Semantic Density in Cycle III. The development of average scores shows that students gradually move from simply performing server and client roles to being able to explain task division, parallel processing, load balancing, latency, and bottlenecks more analytically. Therefore, compared to hands-on or simulation-based learning that primarily provides visualization and operational experience (Dzhumatovich & Salimrouhi, 2025), the integration of the Semantic Wave in this study provides a pedagogical structure that can help students repackage concrete experiences into more dense, systematic, and applicable conceptual knowledge. These findings are also supported by increased student engagement, discussion, collaboration, and reflection, which confirms that learning technology will be more meaningful when used as a space for interaction, exploration, and knowledge construction, rather than simply as a demonstration tool (Bond et al., 2020; Bedenlier et al., 2020; Maton, 2013; Yew & Goh, 2016).

### 3.5. Implication

This research has an impact on improving informatics learning outcomes in high school. It contributes to the development of more interactive, contextual, and relevant informatics learning media for the digital age, and provides a solution to address students' difficulties in understanding distributed computing concepts more effectively and meaningfully.

### 3.6. Limitations and Future Research

The limitations of this study lie in the limited number of participants, namely 30 students, and the study's implementation, which only covered one class in one school. Therefore, it is recommended that future research involve a larger number of participants and implement classroom action research in multiple schools to ensure stronger generalizability of the findings.

## 4. Conclusion

The development of a distributed computing platform based on Semantic Wave has significantly contributed to improving digital infrastructure literacy among high school students, particularly in distributed computing. The application of the Semantic Wave approach to learning demonstrated that student learning progressed gradually and systematically. Three cycles of Classroom Action Research (CAR) guided students from concrete experiences in Cycle I, to contextual transitions in Cycle II, and to abstract-systemic reasoning in Cycle III. Quantitative data demonstrated consistent improvement in student learning outcomes. Observational data also demonstrated stronger engagement, collaboration, communication, and the ability to connect simulation activities with technical concepts. A key pedagogical contribution of this study is the integration of semantic waves into classroom action research for abstract Informatics topics. This approach helped students experience distributed computing as a tangible and meaningful process before reframing it into concepts such as parallel processing, load balancing, throughput, latency, and synchronization. Therefore, Semantic Wave-based learning is recommended for Informatics topics that are abstract, process-based, and difficult to observe directly.

## Author Contributions

Eka Fitrajaya Rahman: Conceptualization, Methodology, Supervision, review. Erna Piantari: Conceptualization, Methodology, Supervision. Renisa Nur Kamelia Putri: Investigation, Data curation, Formal analysis, Writing. Dwi Fitria Al Husaeni: Writing, Review & Editing.

## Funding

No funding support was received.

## Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

## Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

## Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.


ISSN: 2797-3174

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ISSN: 2797-3174